

# Constraints on Inflationary Vacuum Choices.

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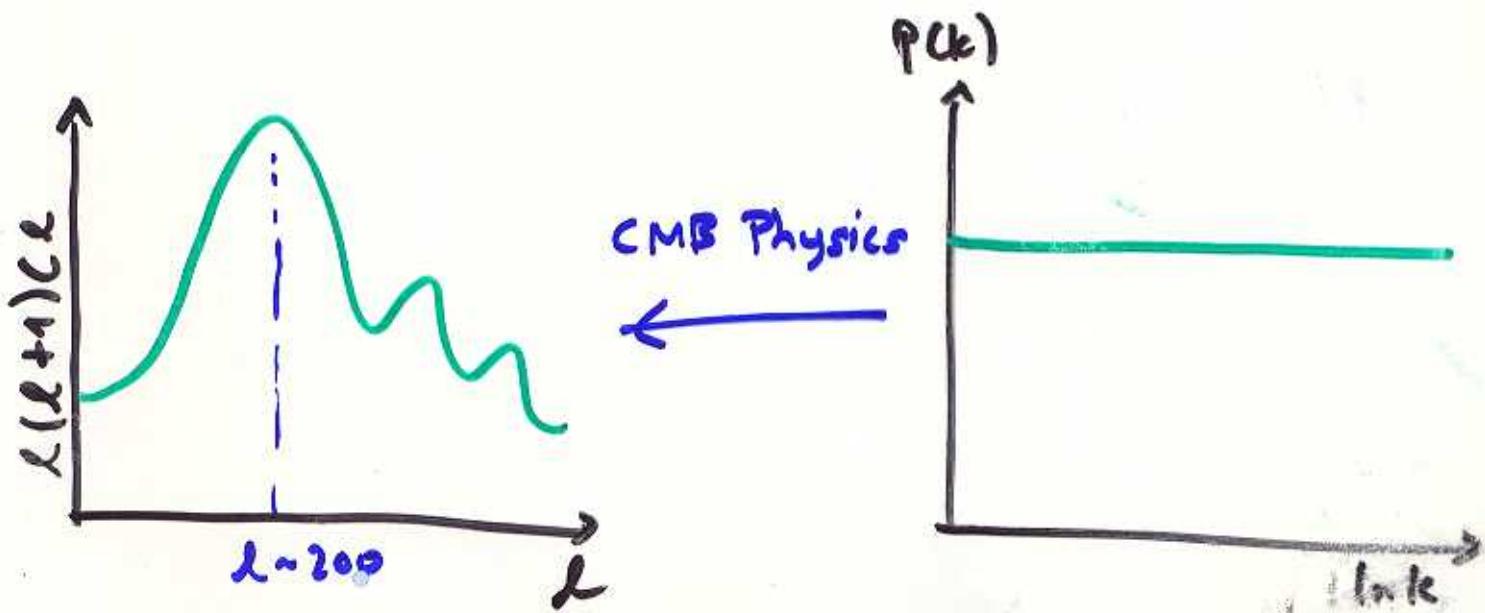
ast-ph/0303103!

# Outline

- A model for parameterizing vacuum choices during inflation
- WMAP-CBI-AcBAR constraints on corrections
- Cosmic Variance Limited "can we ever see those corrections" experiment simulation

# The CMB as a probe of the Primordial power spectrum

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$$P(k) \sim A k^{n_s - 1}$$

amplitude      scalar spectral index

$$A \sim 10^{-10}$$

$$n_s \sim 0.99$$

# Primordial Power Spectrum from Inflation

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By far, the most successful model of power spectrum generation is **Inflation**.

Ingredients:

- Classical General Relativity with a slow-roll scalar field

$$S = \int d^4x \frac{R}{2} - \frac{1}{2} (\partial\phi)^2 - V(\phi)$$

$$\left. \begin{aligned} \epsilon &= \frac{M_p^2}{2} \left( \frac{v'}{v} \right)^2 \\ \eta &= M_p^2 \left( \frac{v''}{v} \right) - \epsilon \end{aligned} \right\} \text{slow-roll limit}$$

- Quantized perturbations : QFT on curved space-times. (Initial Conditions)

# Vacuum Choices w/ a Cut-off

Evolution of perturbations is described by the Mukhanov "v-eqn"

$$V''_k + \left(k^2 - \frac{z''}{z}\right)V_k = 0$$

$$z = a\sqrt{E}$$

Choice of vacuum state  $|0\rangle$

$\Leftrightarrow$

Initial Conditions for  $V_k(\eta_0)$ ,  $V'_k(\eta_0)$

In Minkowski spacetime, the choice of vacuum is just the usual ones. But in a curved space time, with a mode cut-off, we expect there will be corrections to these "reasonable" choices.

In particular, we want the corrections to

- vanish when  $k/a \gg H$
- not vanish when  $\lambda < \infty$

A general parameterization of the vacuum state is

$$v_k(\eta_0) = \frac{e^{-i\phi}}{ik} \left( 1 + \frac{x+y}{2} \theta_0 + O(\theta_0^2) \right)$$

$$v'_k(\eta_0) = -i\sqrt{k} e^{i\phi} \left( 1 + \frac{x+y}{2} \theta_0 + O(\theta_0^2) \right)$$

$$\theta_0 = \frac{(a/k)}{H^m} \Big|_{\eta_0}, \quad \theta_0 \rightarrow 0 \text{ when } k/a \gg H$$

$x, y$  complex parameters depending on vacuum prescription per mode.

Note there are 2 sources of ambiguity

- choice of vacuum prescription
- time, per mode, that this choice is made ( $\eta_0(k)$ )

$$\frac{X+Y}{2} \quad \theta_0$$

### Vacuum prescription

e.g.  $X=0, Y=0$  adiabatic vac

$X=-i, Y=i$  Danielsson

PRD 66, 023511

### Choice of $\eta_0(k)$

"Initial Conditions Hypersurface"  
Bazeia et al. hep-th/0302134

Choose  $\eta_0(k)$ , to be the time when each mode crosses the cut-off scale:

$$\checkmark \quad \frac{a(\eta_0)}{k} = \Lambda^{-1} \rightarrow \theta_0 = \frac{H_0}{\Lambda} \left( \frac{k}{k_c} \right)^{-\epsilon} \quad \text{Danielsson 02}$$

alternately, we can choose

$$H(\eta_0) = \Lambda \rightarrow \theta_0 = \left( \frac{H_0}{\Lambda} \right)^{\frac{1}{\epsilon}} \frac{k_c}{k}$$

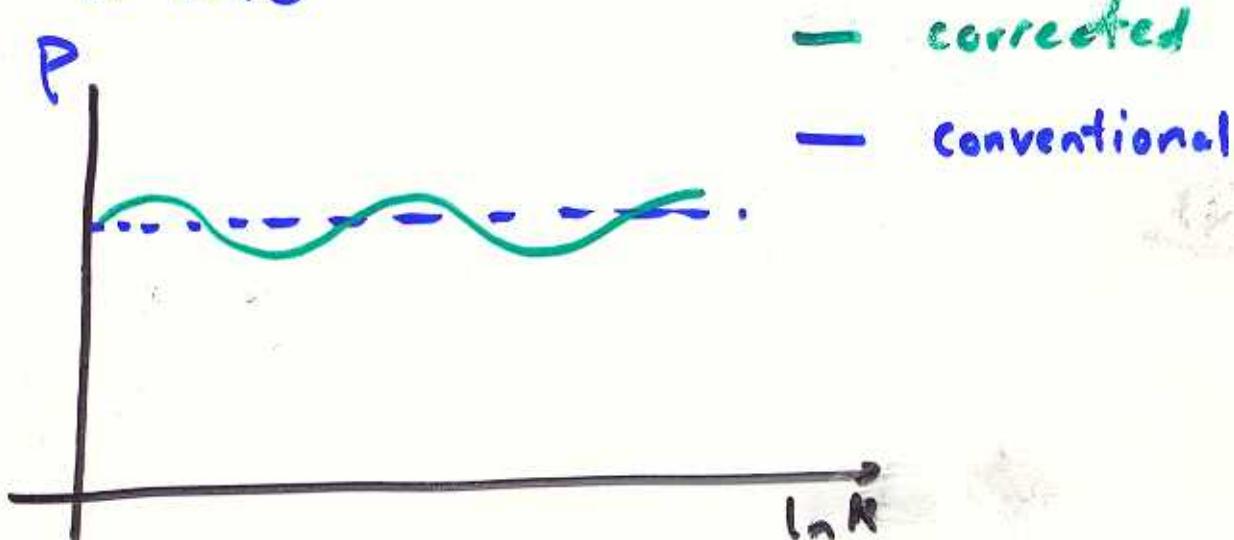
Since  $\Lambda$  is finite or not  $\infty$ ,  $\Rightarrow \theta_0 \neq 0$ .

Final power spectrum :

$$P = P_0^2 \left[ 1 + \theta_0 |x| \cos \left( \frac{\theta_0^2}{\theta_0(1-t)} + \alpha \right) \right]$$

$$\alpha = \psi - 2\pi \left( \frac{3-n_s}{4} \right)$$

$$x = |x| e^{i\psi}$$



- Oscillations give us hope of detecting it
- amplitude is  $\theta_0 |x| \approx |x| \frac{H_0}{\lambda}$
- measurement of frequency  $\frac{\theta_0^2}{\theta_0(1-t)}$  may break  $\theta_0 |x|$  degeneracy
- phase of shifts starting point of oscillation  $\Rightarrow$  cannot be neglected!

# WMAP - CBI - ACBAR constraints

Turns out that the following reparameterization is more sensitive to the data:

$$P = P_0 \left[ 1 + \lambda \left( \frac{k}{k_*} \right)^{-\epsilon} \cos \left( \frac{\omega}{\epsilon} \left( \frac{k}{k_*} \right)^\epsilon + \alpha \right) \right]$$

$$\lambda \equiv |x| \frac{H_0}{\pi}$$

$$\omega = \frac{2\pi}{1-\epsilon} \frac{\lambda}{H_0} \quad \text{"freq" in } \log \frac{k}{k_*}$$

Priors :

$$\lambda \sim 2 - 2000 \quad \leftarrow \text{dataset}$$

$$\lambda \in [0, 1]$$

$$\omega \in [0, 20] \quad \leftarrow \text{validity of CAMB code}$$

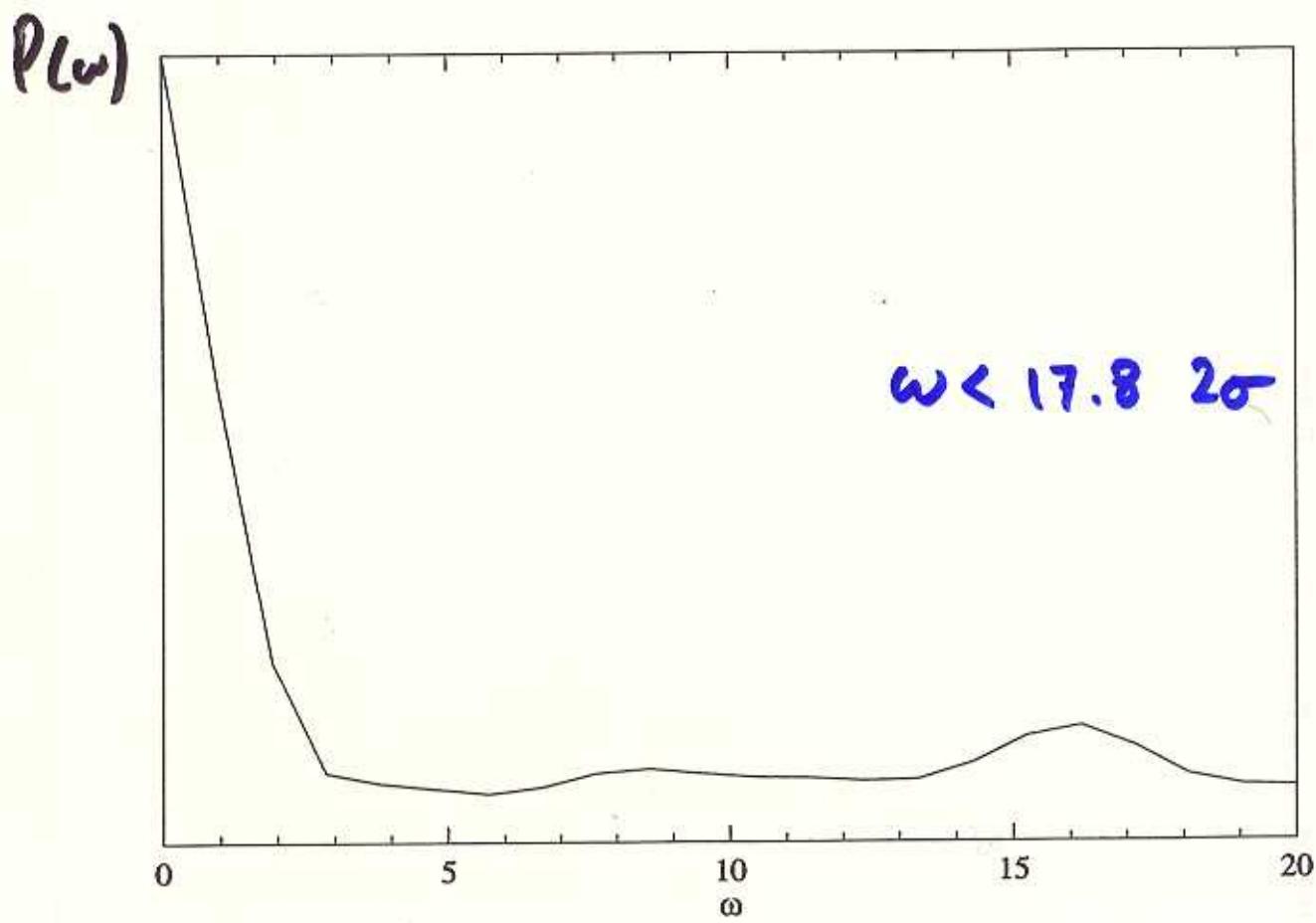
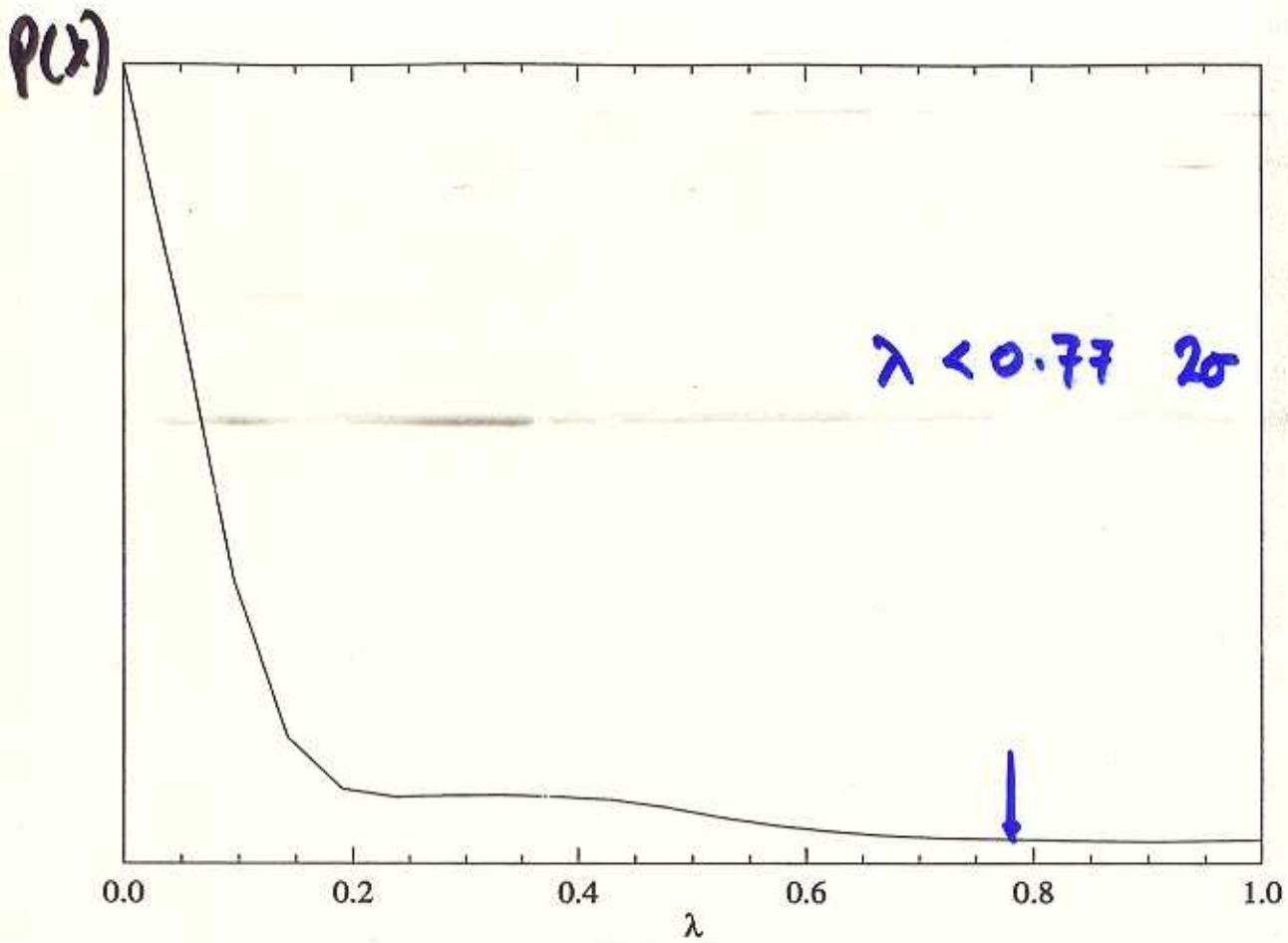
$$\epsilon \in [0, 0.2]$$

$$\alpha \in [0, 2\pi]$$

$$n_s \in [0.9, 1.2]$$

$$l \in [5, 100]$$

we float  $n_{\text{reh}}$ ,  $\Omega_{\text{reh}}$ ,  
 $H_0$ ,  $z_{\text{re}}$



- Essentially no constraint on  $w$ .
- $\lambda = |x| \frac{H_0}{\Lambda} < 0.77$   
 (If impose  $x \approx O(1)$ ,  $\Rightarrow \frac{H_0}{\Lambda} \approx O(1)$ )  
 $\Rightarrow$  expansion break down.

# Cosmic Variance Limited Experiment

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Imagine an ideal experiment (e.g. super-duper-Planck).

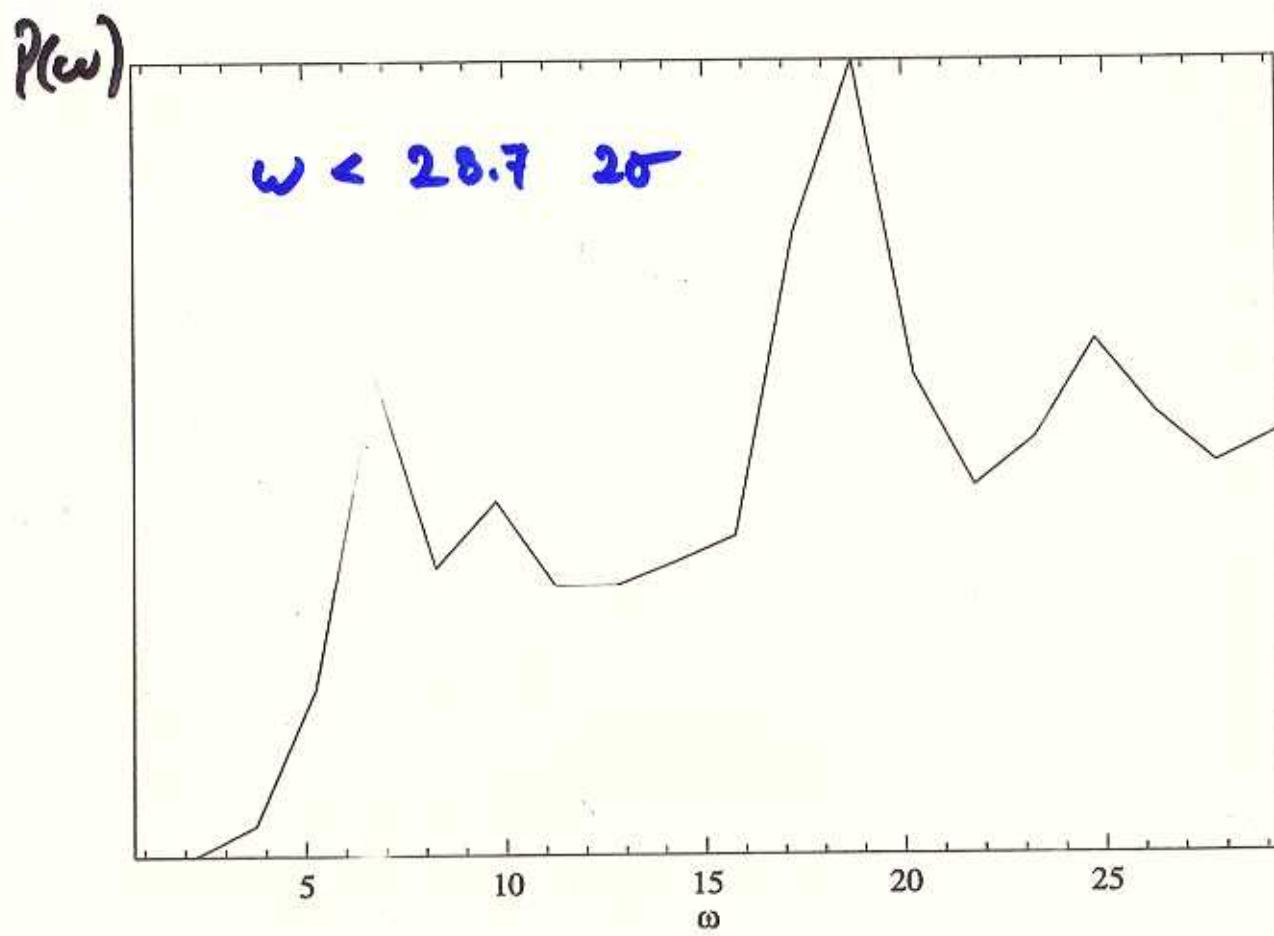
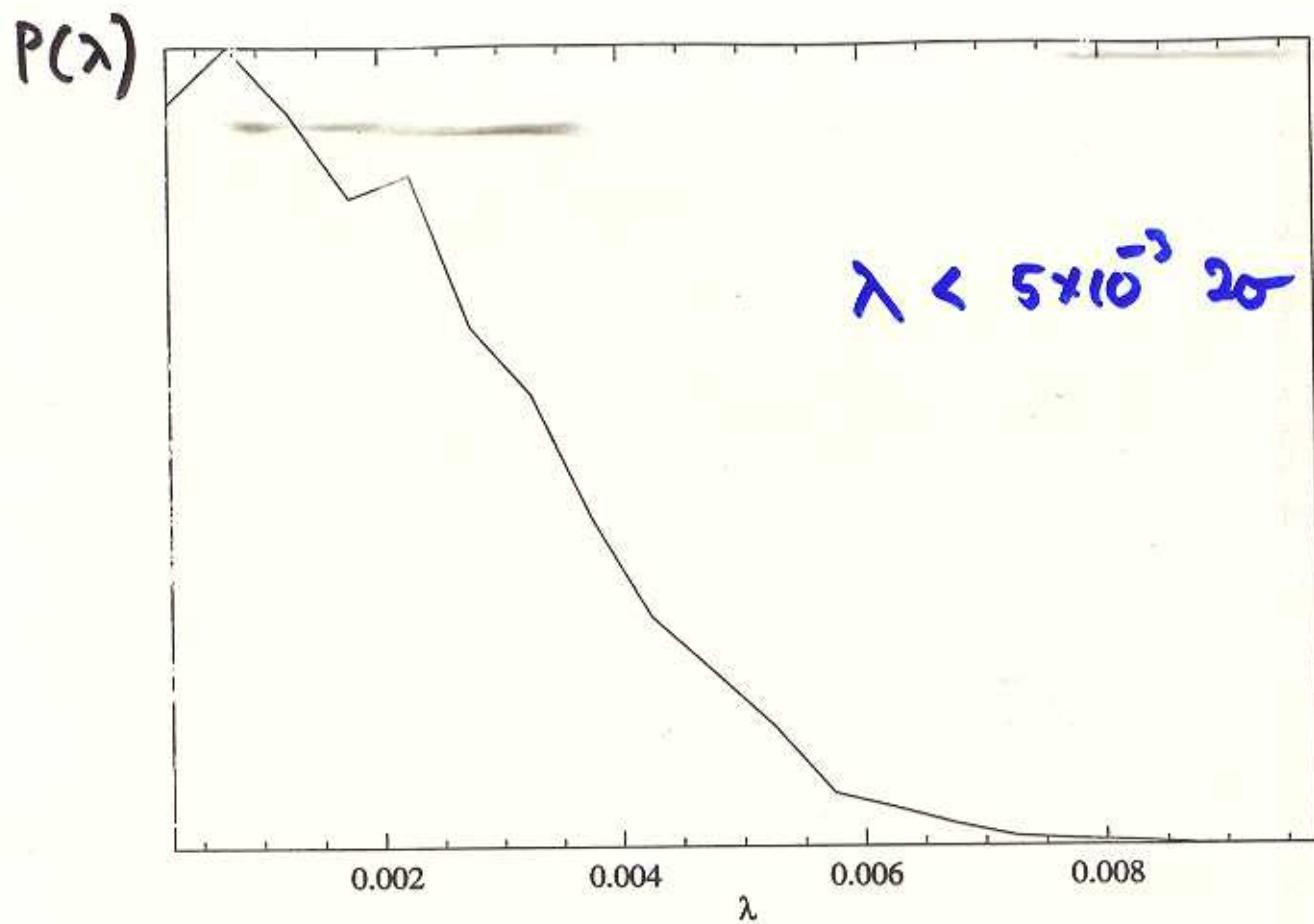
Ask the question :

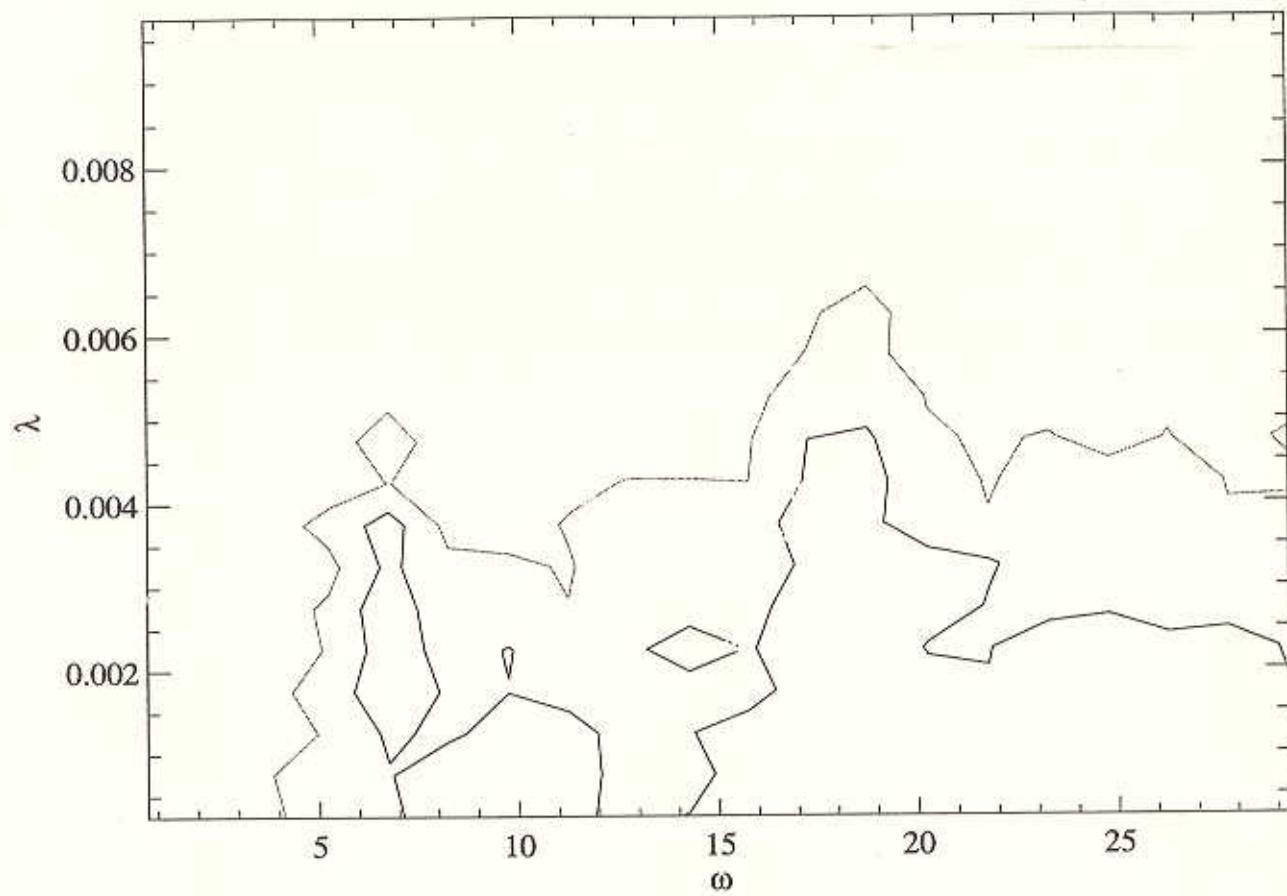
What would the range of parameters the theory has to take before it becomes statistically distinguishable from the null (completely boring) model?

Motivation: we want to know if the CMB will ever be, theoretically, a probe of cut-off "plankian" physics.

"Data": Null Model, fix cosmology (best fit WMAP)

Priors:  $\Omega \in [2, 2000]$  } lensing and other  
 $w \in [0, 30]$  } foregrounds (S2 etc...)  
(The rest the same as previous)





Interpretation: if the "real" universe is described by such a model, then it has to fall outside the  $2\sigma$  contours to be distinguishable (statistically) from the null model.

If  $|x| \sim 0(1)$ , we can probe physics at  $H_*/\Lambda \gtrsim 10^{-2}$ , or if  $H_* \sim 10^{16} \text{ GeV}$   
 $\Rightarrow$  we may probe "planckian" physics at  $\Lambda \sim 10^{18} \text{ GeV}$ !

# Conclusions

- WMAP - CBI - ACBAR has little constraining power on oscillatory type corrections to the CMB
- CV Limit experiment may probe physics up to  $10^{18}$  GeV.  
Caveat : competing models
  - Kaloper, Kaplinghat hep-th/0307016
  - Burgess et al astro-ph/0304225